Particle-Astrophysics Theory At Fermilab

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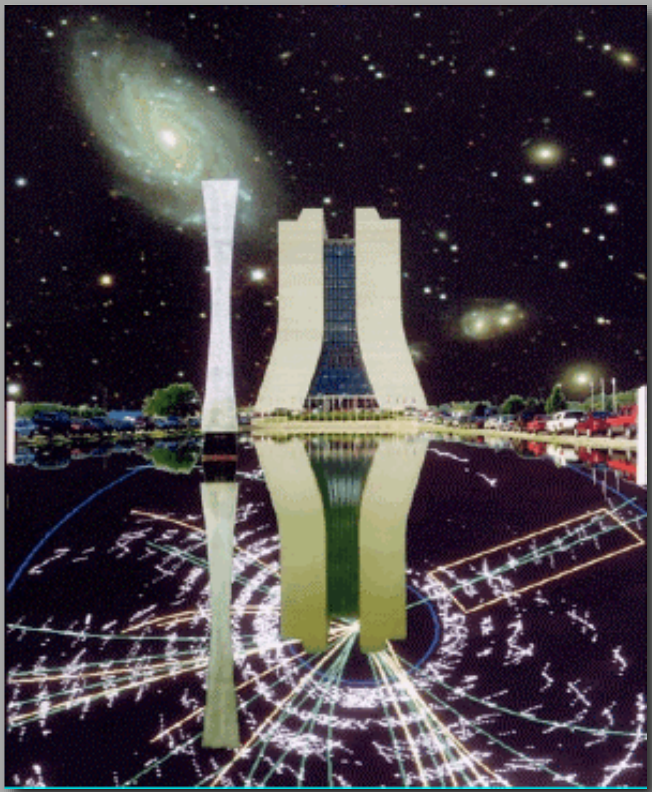

Annual DOE Review
September 26, 2007

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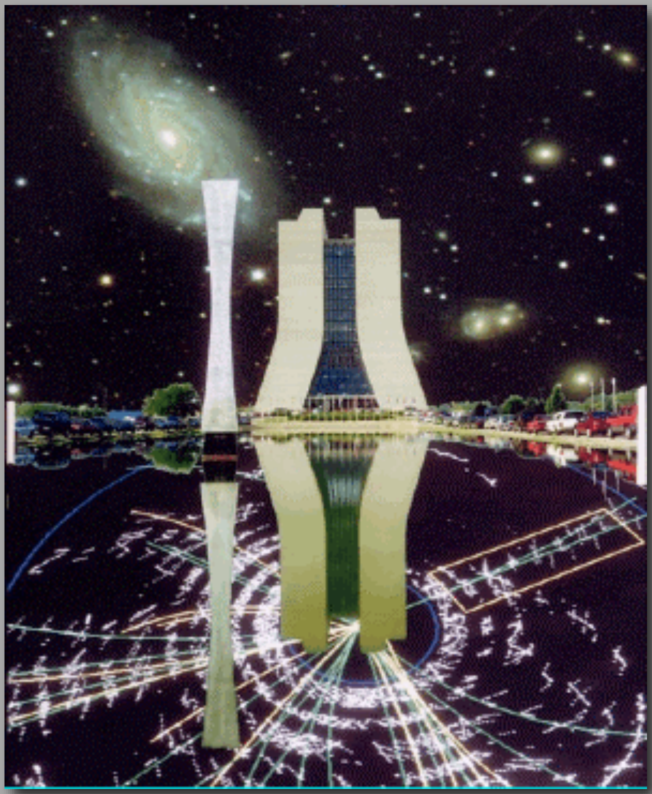

How To Study Particle Physics?

•Traditionally, our greatest tools for studying particle physics have been collider experiments

-Incredibly high luminosity beams
-Very large numbers of collisions can be observed

-Energy is limited, however, by technology/cost:
Tevatron (1.96 TeV)
LHC (14 TeV)

How To Study Particle Physics?

- Astrophysical accelerators are known to accelerate particles to at least ~10^{20} eV (center-of-mass energies of *hundreds of TeV*)

- Opportunities to study stable or extremely long lived particles (neutralinos, or other WIMPs, axions, topological defects, etc.)

- Extremely long baseline measurement possible

- Provides a natural complementarity with collider experiments

Activity in Theoretical Particle-Astrophysics at Fermilab

- **Particle Dark Matter**
- **High Energy Cosmic Ray and Neutrino Physics**
- **Early Universe Particle Cosmology**
- **Exotic Cosmic Ray Physics**

Activity in Theoretical Particle-Astrophysics at Fermilab

CDMS, COUPP

- **Particle Dark Matter**
- **High Energy Cosmic Ray and Neutrino Physics**

Minos, MiniBooNE

- **Early Universe Particle Cosmology**

Tevatron

- **Exotic Cosmic Ray Physics**

Pierre Auger Observatory

Activity in Theoretical Particle-Astrophysics at Fermilab

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- **Early Universe Particle Cosmology**

Tevatron

- **Exotic Cosmic Ray Physics**

Pierre Auger Observatory

- **Physics Beyond the Standard Model (SUSY, extra dimensions,…)**

Particle Theory Group

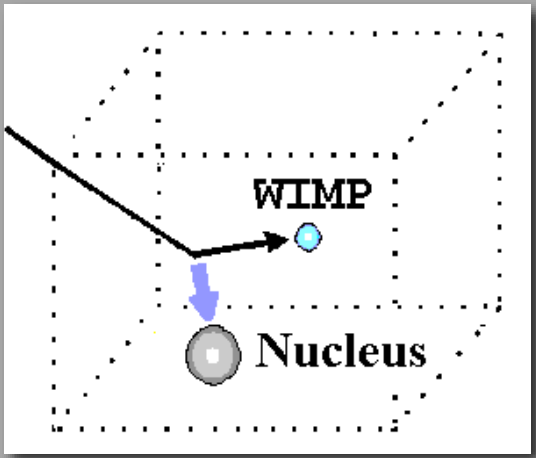
Particle Dark Matter

- Carena, **Hooper** & **Vallinotto**, The interplay between collider searches for supersymmetric Higgs bosons and direct dark matter experiments (PRD, hep-ph/0611065)
- **Hooper** & Zaharijas: Distinguishing supersymmetry from universal extra dimensions or Little Higgs models with dark matter (PRD, hep-ph/0612137)
- **Hooper** & Profumo: Dark matter and collider phenomenology of universal extra dimensions (Phys. Rept., hep-ph/0701197)
- **Hooper** & **Serpico**:Angular signatures of dark matter in the diffuse gamma ray spectrum (JCAP, astro-ph/07021328)
- **Hooper**, Kaplinghat, Strigari & Zurek: MeV dark matter and small scale structure (submitted to PRD, arXiv:0704.2558)
- **Hooper**, Finkbeiner & Dobler: Evidence of dark matter annihilations in the WMAP haze (PRD, arXiv:0705.3655)
- Dobrescu, **Hooper**, Kong & Mahbubani: Spinless photon dark matter from two universal extra (submitted to PRD, arXiv:0706.3409)
- Kachelriess & **Serpico**: Model-independent dark matter annihilation bound from the diffuse gamma ray flux (arXiv:0707.0209)

How Do We Identify Dark Matter?

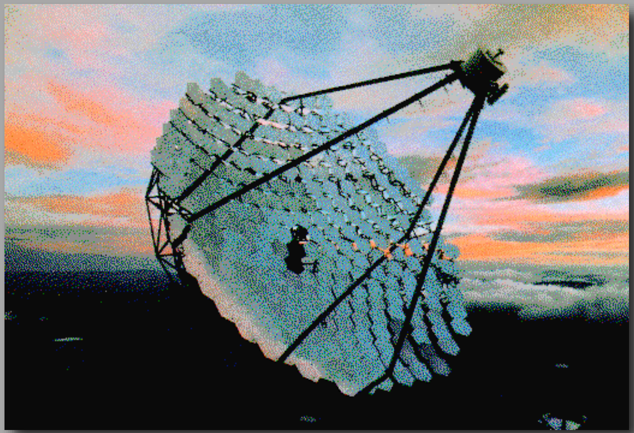
Direct Detection

-Momentum transfer to detector through elastic scattering



Indirect Detection

-Observation of annihilation products (γ, ν, e+, $\bar{p}$, etc.)



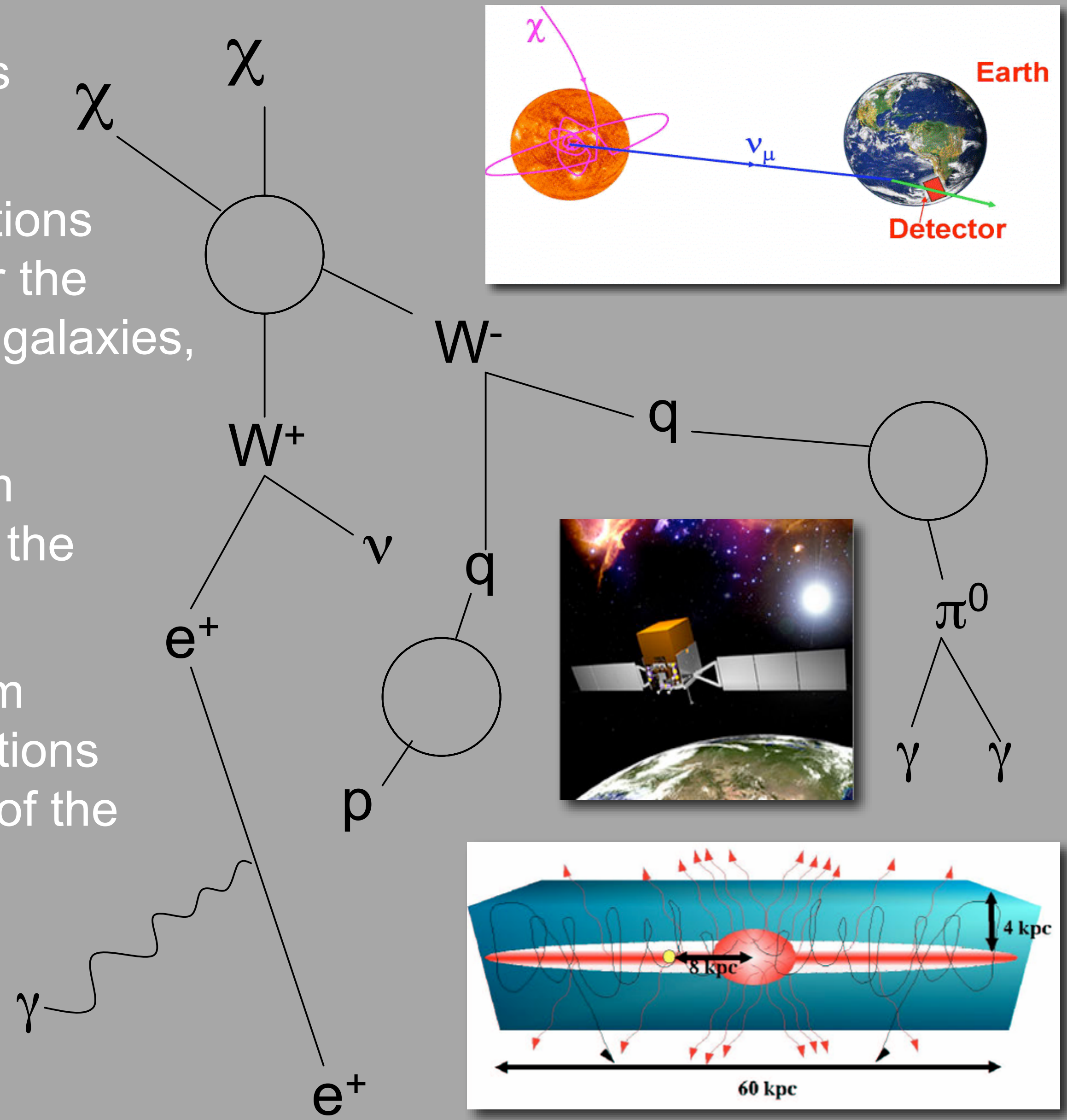
Indirect Detection of Dark Matter

Neutrinos from annihilations
in the core of the Sun

Gamma Rays from annihilations
in the galactic halo, near the galactic center, in dwarf galaxies, etc.

Positrons/Antiprotons from
annihilations throughout the galactic halo

Synchrotron Radiation from
electron/positron interactions with the magnetic fields of the inner galaxy



Detecting Dark Matter With Gamma-Rays

•A great deal of our recent work has focused on how to best use gamma ray astronomy to identify dark matter annihilation

•Both spectral and angular information will be present in future GLAST data - Important to fully exploit all information

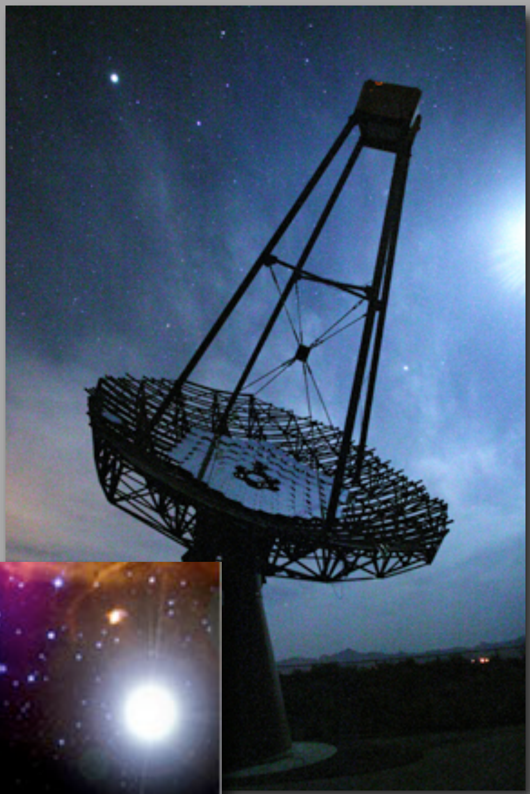
•Angular signatures include:

-Anisotropy due to the motion of the solar system (the cosmological *and* galactic Compton-Getting effect)

-Effects of nearby dark matter structures

-Angular distribution due to offset position of the Sun

(**Hooper** & **Serpico**, JCAP, astro-ph/0702328)



Gamma Ray Astronomy At Fermilab?

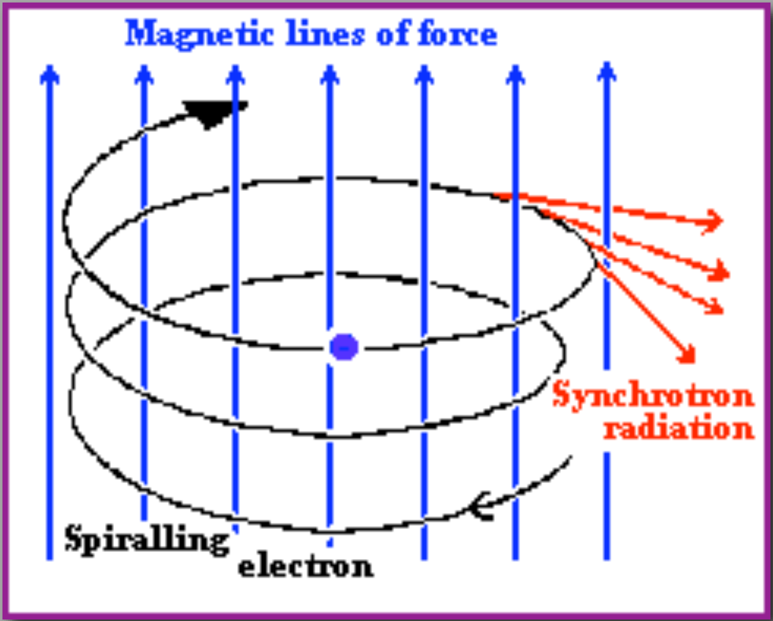
The next generation of Atmospheric Cerenkov Telescopes

- Following the successes of HESS, VERITAS and MAGIC, the gamma ray astronomy community has started to look ahead
- High sensitivity, low threshold, large field-of-view telescope arrays
- Building interest among Fermilab experimentalists

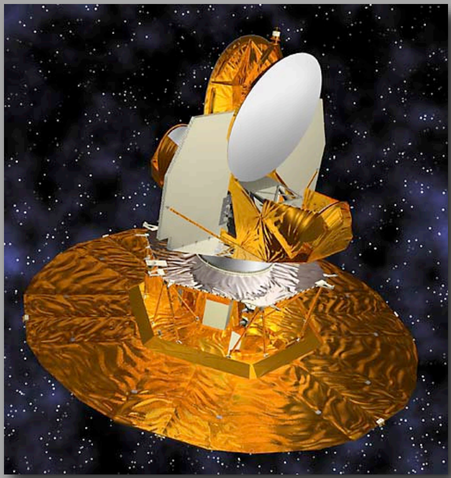
- Fermilab involvment in AGIS or another next generation ACT program?

Indirect Detection With Synchrotron and Inverse Compton Radiation

•Electrons/positrons produced in dark matter annihilations inverse Compton scatter with starlight and emit synchrotron photons as they propagate through the galactic magnetic fields

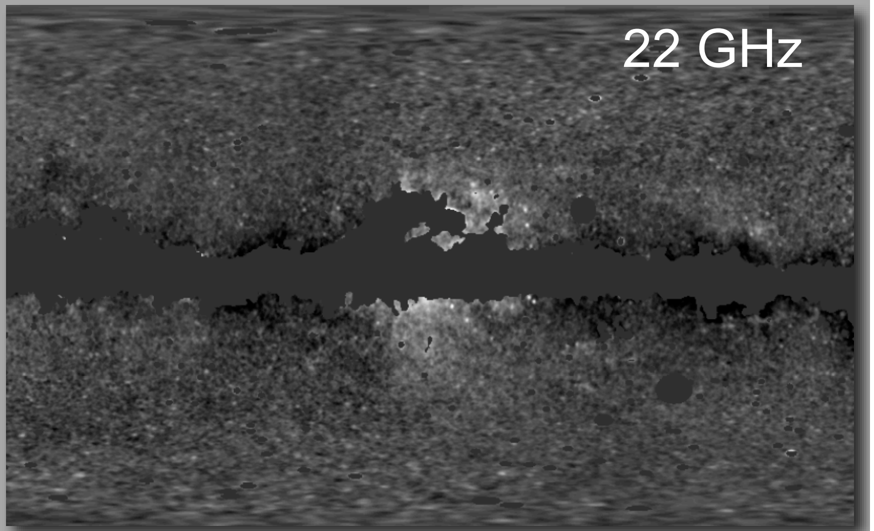


•These annihilation products have been studied far less than prompt gamma rays, antimatter or neutrinos



•For electroweak-scale dark matter, the resulting synchrotron radiation falls within the frequency range of CMB experiments, such as WMAP

Dark Matter in the WMAP Sky



•Excess of hard synchrotron is seen in the inner galaxy by WMAP

•Indicates a new population of energetic electrons/positrons in the inner galaxy

•Too hard to be supernovae shocks

• Too extended to be a singular event, such as a GRB

$\Rightarrow$ Very Difficult to explain astrophysically

•Consistent with a cusped halo profile and a 100-1000 GeV WIMP, with an annihilation cross section of ~3×10^{-26} cm^3/s

<u>Hooper</u>, Dobler & Finkbeiner: PRD, arXiv:0705.3655

Ultra-High Energy Particle-Astro Physics

- Cucoco, Miele & **Serpico**: Evidence for nearby universe structures in the ultrahigh energy sky (arXiv:0706.2864)
- Cucoco, Hannestad, Haugbolle, Miele, **Serpico** & Tu: The signature of large scale structures on the very high energy gamma-ray sky (JCAP, astro-ph/0612559)
- Cucoco, Miele & **Serpico**: First hints of large scale structures in the ultrahigh energy sky? (PRD, astro-ph/0610374)
- Cucoco, Mangano, Miele, Pastor, Perrone, Pisanti & **Serpico**: Ultrahigh energy neutrinos in the Mediterranean: Detecting tau and muon neutrinos with a cubic kilometer telescope (JCAP, astro-ph/0609241)
- Anchordoqui, Goldberg, **Hooper**, Sarkar & Taylor: Predictions for the cosmogenic neutrino flux in light of new data from the Pierre Auger Observatory (submitted to PRD, arXiv:0709.0734)
- Anchordoqui, **Hooper**, Sarkar, & Taylor: High-energy neutrinos from astrophysical accelerators of cosmic ray nuclei (astro-ph/0703001)

Ultra-High Energy Particle-Astro Physics

What is the origin of the Ultra-High Energy Cosmic Rays?

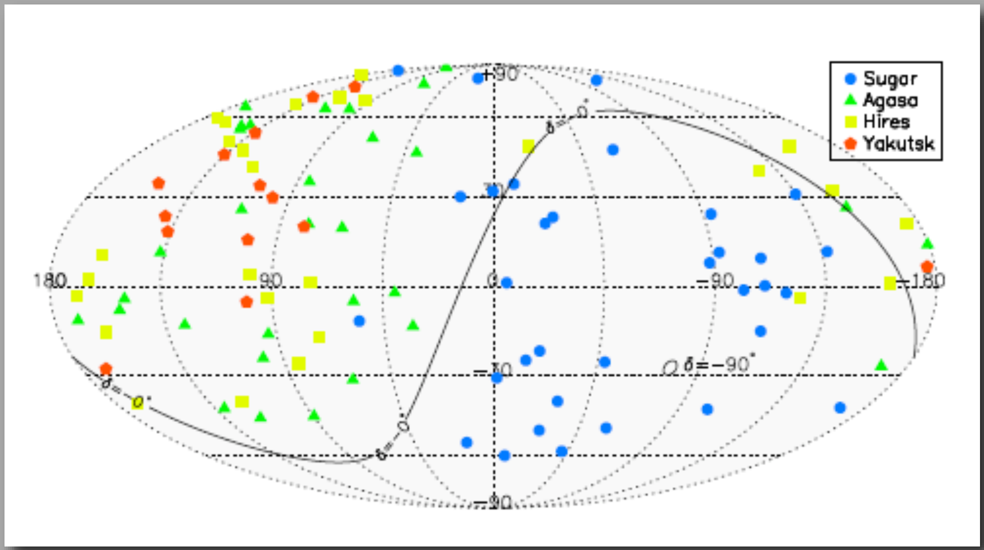
- The Pierre Auger Observatory and other UHECR experiments have taught us a great deal about the highest energy particles observed in nature (mixed chemical composition, GZK suppressed spectrum)
- Still no local sources have been identified
- Without sources, the origin of these particles remains unknown
- Neutrino and gamma-ray observations, in addition to further cosmic ray data will likely be needed to resolve this question

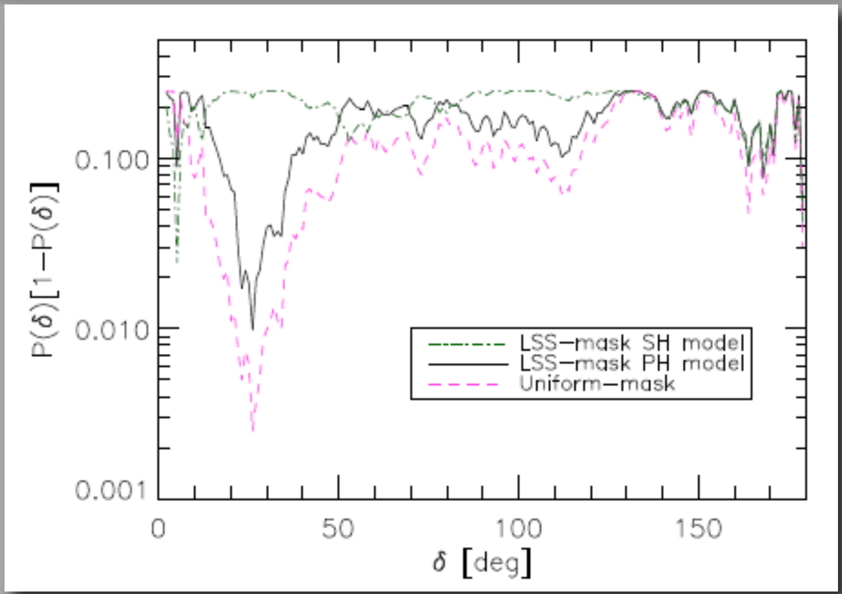
Ultra-High Energy Particle-Astro Physics

- Looking for clustering in UHECRs is the first step toward identifying sources

- The highest energy events in pre-Auger data match particularly well with the structure of the nearby universe ($z < 0.02$)

- Auger data will dramatically improve our understanding of these issues



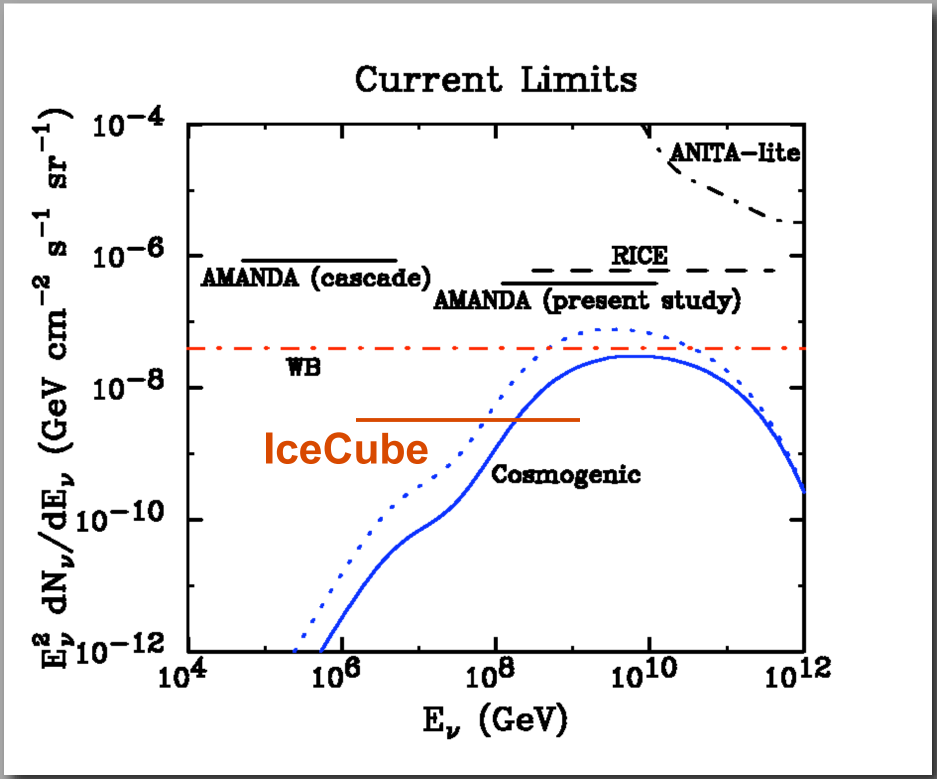


(Cuoco, Miele & **Serpico** 2007)

Ultra-High Energy Particle-Astro Physics

The UHECR Connection To High Energy Neutrino Astronomy

- Neutrinos produced in UHECR propagation (cosmogenic neutrinos) has long been thought of as a guaranteed source of observable UHE neutrinos

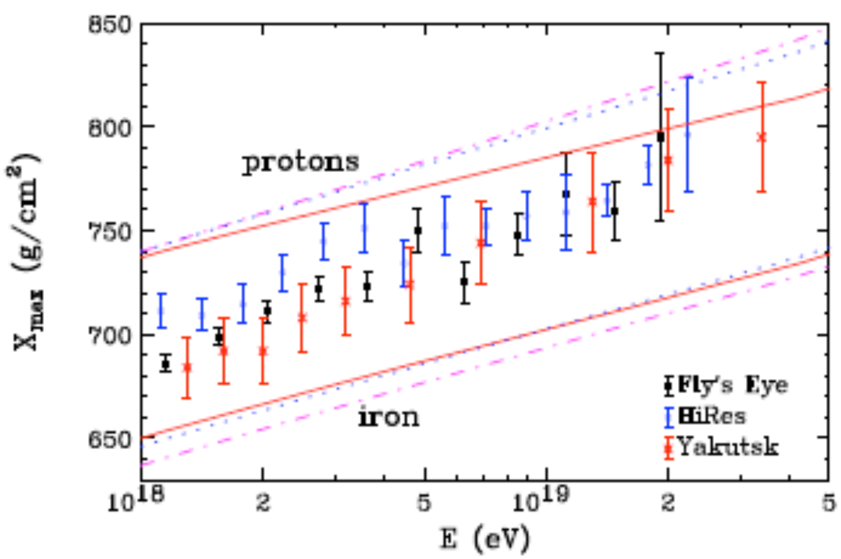


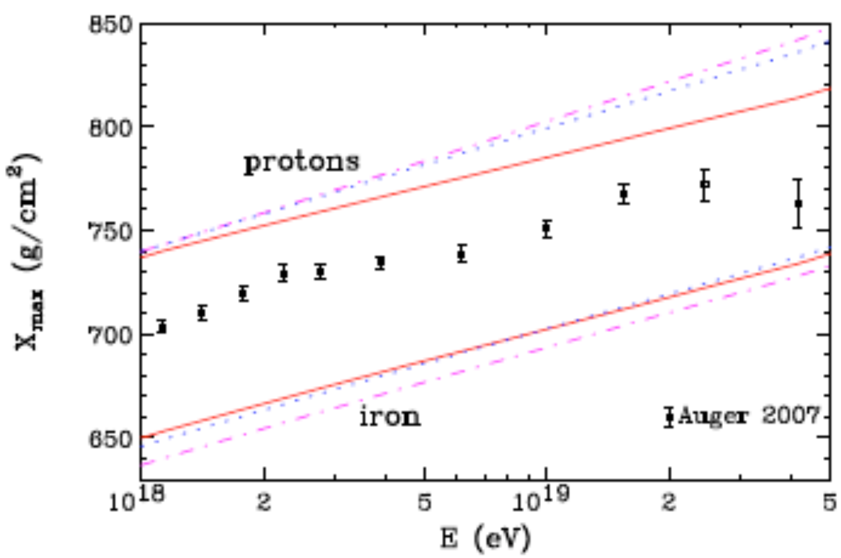
(Halzen & **Hooper** 2006)

Ultra-High Energy Particle-Astro Physics

The UHECR Connection To High Energy Neutrino Astronomy

The UHECR spectrum, however, appears to consist of nuclei and not only protons, however, unlike has traditionally been assumed



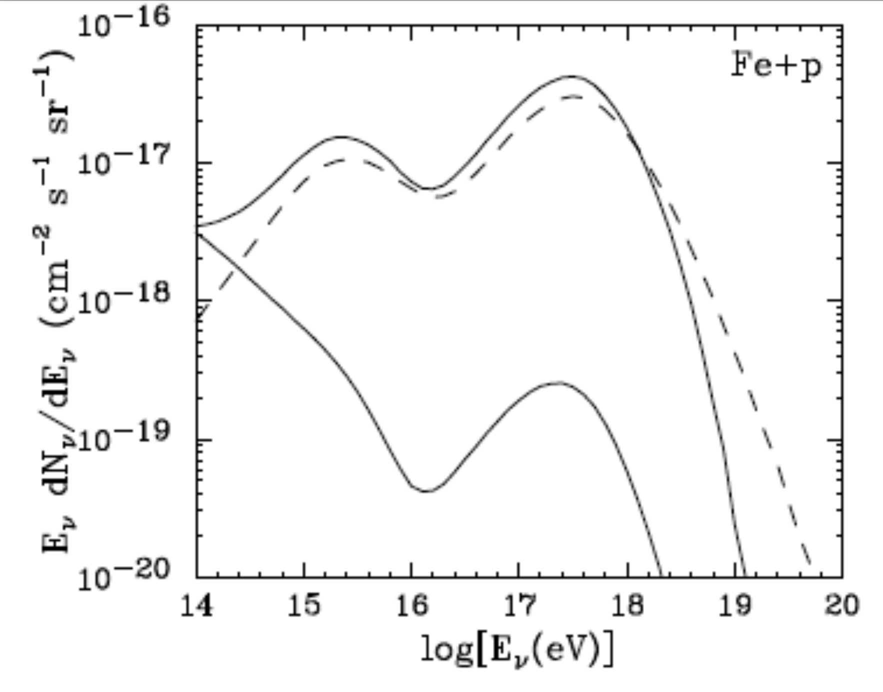


A nuclei dominated UHECR spectrum can lead to the suppression of the cosmogenic neutrino flux

Ultra-High Energy Particle-Astro Physics

The UHECR Connection To High Energy Neutrino Astronomy

- The current Auger data is consistent with a models which predict a wide range of cosmogenic neutrinos fluxes (~1 event per year to ~1 event per century)
- More Auger data will allow us to make more accurate predictions
- A profound connection exists between UHE neutrino and cosmic ray physics



(Anchrodoqui, Goldberg, **Hooper**, Sarkar & Taylor, arXiv:0709.0734)

The Early Universe

- Mirizzi, Montanino & **Serpico**:Revisiting cosmological bounds on radiative neutrino lifetime (arXiv:0705.4667)
- Pisanti, Cirillo, Esposito, Iocco, Mangano, Miele & **Serpico**: PArthENoPE: Public Algorithm Evaluating the Nucleosynthesis of Primordial Elements (arXiv:0705.0290)
- Iocco, Mangano, Miele, Pisanti & **Serpico**: The path to metallicity: Synthesis of CNO elements in standard BBN (PRD, astro-ph/0702090)
- **Serpico**: Cosmological neutrino mass detection: The best probe of neutrino lifetime (PRL, astro-ph/0701699)

Exotic Cosmic Ray Physics, etc…

- Mirizzi, Raffelt & **Serpico**: Signatures of axion-like particles in the spectra of TeV gamma-ray sources (PRD, arXiv:0704.3044)
- **Hooper** & **Serpico**: Detecting axion-like particles with gamma ray telescopes (submitted to PRL, arXiv:0706.3203)
- **Hooper**: Detecting MeV gauge bosons with high-energy neutrino telescopes (PRD, hep-ph/0701194)
- **Jackson:** Interactions of cosmic superstrings JHEP (arXiv:0706.1264)
- **Jackson:** A Note on Cosmic (p,q,r) Strings PRD (hep-th/0610059)

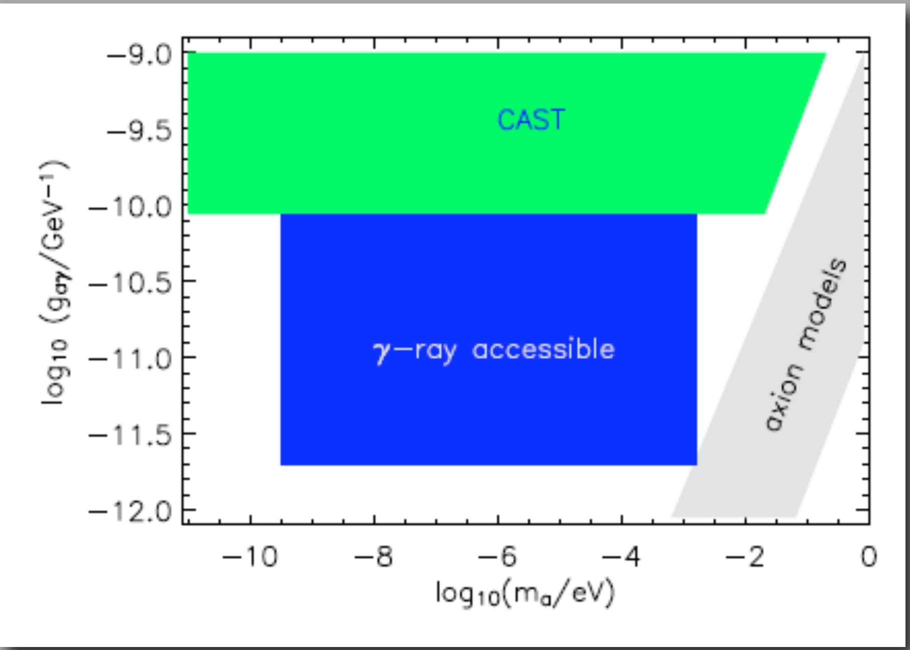
Exotic Cosmic Ray Physics

Gamma ray astronomy and axion-like particles

•There has been a recent resurgance in interest in axions and axion-like particles

•In the presence of magnetic fields, photons and axions can mix via the term:

$$\mathcal{L}_{a\gamma} = -\frac{1}{4}\, g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a = g_{a\gamma}\, \mathbf{E}\cdot\mathbf{B}\, a$$



•May occur only at high energy, providing a natural opportunity for gamma ray astronomy

•Potential way to test/detect models beyond the reach of other axion probes

•Also theory group interaction with the GammeV experiment

(**Hooper** & **Serpico**: arXiv:0706.3203; Mirizzi, Raffelt & **Serpico**, PRD, arXiv:0704.3044)

Summary and Conclusions

- Research in particle dark matter, ultra-high energy cosmic rays, high-energy neutrinos, and other areas of particle-astrophysics are very active and exciting at Fermilab

- Interaction with experimental groups (CDMS, Pierre Auger, etc.) and particle theory group make Fermilab an excellent place to study this multi-disciplinary science

- Strong interactions with particle theory group (joint pizza meetings/seminars) and experimentalists (munch, Thursday chalk talk)

THANK YOU